

MECHANICAL DESIGN OF AN AUTOMATED VEHICLE DRIVING SYSTEM
FOR DRIVE CYCLE TESTING

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For my beloved mother Aisah bt Haji Bujang and my beloved father Saini Bin Lajim. I would like to take this opportunity to thank you for all the support, motivation and guidance from the beginning until the end of this project. Then, to my supervisor Dr Wan Saiful-Islam Bin Wan Salim, thank for all your guidance from the beginning until the end of this project. Last but not least, to all my friends who have helped me directly or in-directly. I would like to dedicate my appreciation for all your sacrifice and valuable advice for me



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Abstract

This thesis describe the mechanical design process for an automated drive cycle testing system. Drive cycle is a graph containing series of vehicle speed data versus time. The main reason for drive cycle existence is to analyse the air pollution that is emitted by vehicle engines through combustion process. It is also can be used as a reference for vehicle manufacturer in order to design their engine, which may reduce the possibility of air pollution release to the air and also to reduce the fuel usage to reach higher distances travel per litre fuel. The mechanical design for automated drive cycle system is needed in order to eliminate human as a medium that will run the drive cycle test. The purpose for human driver elimination is due to susceptible human error, the inconsistency in driving pattern and also the need of training for the driver to run the drive cycle test. There are two objective for this project, which is to design a mechanism that can be used to control a passenger vehicle according to standard drive cycles and to adapt the mechanism with a separate closed-loop control system to enable transient speed-load testing of a vehicle. This objective will be done on a specific vehicle which is Perodua Myvi with automatic gear shifting. There are several findings that related to vehicle control which eliminate human as the handler. From the finding and the requirement to work on a small space area, the new concept for mechanical design is needed. The flow for design process that will be conducted is based on the Pahl and Beitz design method. Referring to the step in the design method, the step will go through several estimation and task specification such as defining task, conceptual design, embodiment design, analysis and detail design that will help in designing the product. The fabrication process give out many challenges and the idea to overcome the problem is describe in the thesis.

Abstrak

Tesis ini menghuraikan rekabentuk mekanikal untuk sistem pemanduan berkala automatik. Pemanduan berkala adalah graf yang mengandungi kumpulan data kelajuan kenderaan melawan masa. Tujuan utama kewujudan pemanduan berkala adalah untuk mengkaji pencemaran udara yang disebarkan oleh kenderaan proses pembakaran kenderaan. Ianya juga boleh dijadikan sebagai garis panduan untuk pengeluaran kenderaan dalam proses rekabentuk enjin mereka, yang mana boleh mengurangkan kemungkinan pembebasan udara tercemar dan mengurangkan penggunaan minyak untuk lebih perjalanan per litre minyak. Rekabentuk mekanikal untuk system pemanduan berkala automatik diperlukan untuk menyingkirkan manusia sebagai pemandu ujian berkala. Ini adalah kerana kemungkinan untuk berlakunya kesilapan pemandu, keadaan corak pemanduan yang tidak sekata dan keperluan latihan memandu untuk pemandu memandu ujian pemanduan berkala. Terdapat dua objektif untuk project ini, iaitu menghasilkan mekanisma yang boleh mengawal kenderaan mengikut standard pemanduan berkala dan menggunakan sistem pengawalan tertutup pada mekanisma rekabentuk untuk melakukan ujian daya kelajuan kenderaan. Objectif ini akan dilaksanakan pada kenderaan Perodua Myvi yang menggunakan sistem automatik. Terdapat beberapa kajian yang berhubung kait dengan penyingkiran manusia sebagai pengendali. Hasil dari kajian dan keperluan untuk bekerja di tempat yang kecil, rekabentuk mekanisma baru diperlukan. Proses rekabentuk akan merujuk kepada method Pahl and Beitz. Merujuk kepada perjalanan proses rekabentuk, proses ini akan melalui beberapa penilaian dan pengkhususan kerja seperti penentuan kerja, konsep rekabentuk, penjelmaan rekabentuk, analisis dan rekabentuk terperinci produk. Proses fabrikasi memberi banyak cabaran dan idea untuk mengatasi masalah dinyatakan di dalam tesis.

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LIST OF SYMBOL AND ABBREVIATIONS

NO ₂	-	Nitrogen Dioxide
PM ₁₀	-	Particulate Material Under 10µm
PM _{2.5}	-	Particulate Material Under 2.5µm
NO _x	-	Nitrogen Oxides
CO	-	Carbon Monoxide
SO ₂	-	Sulphur Dioxide
km/h	-	Kilometer Per Hour
s	-	Time In Second



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CHAPTER 1

INTRODUCTION



Air pollution or air pollution caused by human activity is divided into two cases, whether the source is stationary or mobile. Stationary source is referring to factory, farm and house. Mobile source is referring to transport car, truck, buses and others vehicle. Air pollution basically most caused by the mobile. The main substance found release is Particulate Material under $10\mu\text{m}$ (PM_{10}), Particulate Material under $2.5\mu\text{m}$ ($\text{PM}_{2.5}$), Nitrogen Dioxides (NO_2), Nitrogen Oxides (NO_x) Carbon Monoxide (CO), and Sulfur Dioxides (SO_2) [1]. The car related emission is dangerous and hazardous to the human health. [2]

The step that has been carried out is by controlling the release of those dangerous gas to the surrounding and give a guideline to each source to follow the emission rate of dangerous substance in the air [1]. Each country have their own legislation on this matter. For an example, Environment Air Quality Act 1974 Section 24 and 29, Forestry Act 1984 Section 82, Road Transportation Act 1987(Act 333) Section 66(1) b and Motorized Vehicle (Smoke And Gas Release Control) Law 1944 for Malaysia country [3].

There is legislation that has to be followed to allow the car or internal combustion engine to be manufactured widely. The legislation was first implement in the United States of America (USA) after the oil embargo on 1973 and raise in awareness for the

presence of smoke and other substance in the air that endanger human health and environment [2][1]. The car must pass the regulation during a drive cycle test. This is used to forbid the car that release high amount of dangerous substance to be commercially use. This test also used to be the benchmark for the car manufacturer in order to design the vehicle that meet the emission standard with good fuel economy [4].

This research is carried out to design a mechanism that can control the speed of small-medium passenger cars based on a specific driving pattern called a drive cycle. This mechanism is used to replace the way for on board human operated drive cycle test that commonly driven by trained driver who follow basic speed versus time driving pattern. The speed and time will be set on the program that control the combination of motor, hydraulic pump and actuators. This research mark the beginning of more effective and consistent drive cycle test for vehicles.

1.1 Background of Study

A drive cycle test is conducted either using the car chasing method or by using on board method. The aim for both tests is the same, to determine the fuel consumption and to determine the gas emission from the vehicle based on speed versus time [5][6][7]. From the drive cycle test, the amount of fuel consumption, gas emission and many other data are gathered and used to rate the engine efficiency. Standard drive cycles test are different from each other according to country and region. There Environmental Protection Agency: Federal Test Procedure (EPA: FTP-75) that is use in United States of America region. There is the New Europe Drive Cycle (NEDC) that is used on the Europe region. Japan also has its own drive cycle which are 10 mode, 10-15 mode and 11 mode [7]. In the future, lightweight vehicles will use the harmonize drive cycle test which is known as Worldwide harmonized Light vehicles Test Procedures (WLTP) [8]. Because of these differences drive cycles, improvement on uniformity of the test is needed.

1.2 Problem Statement

The automated vehicle driving system proposed in this study will be used to drive the vehicle following the speed and time specified by the operator. The idea presented is use to eliminate human driver as a medium in the drive cycle test. The purpose on eliminating human driver as a medium to drive the car is to reduce any possibility of error and inconsistencies that comes from the driver [21][22]. This way the drive cycle test can be carried out more efficiently. There are several disadvantages having a human as a driver to run the drive cycle test. The disadvantages is:

- Susceptible to human error
- Inconsistencies in driving pattern
- Required training

In this design, actuator will be used in order to replace the movement made by human foot on the pedal. The actuator used is electrical power actuator that move in linear direction or the movement just like hydraulic cylinder. The brake pedal will experience the same concept when the system need to reduce the speed of vehicle or decelerate. The combination of actuation on both pedals will result in the vehicles being driven according to the preset driving pattern of the drive cycle. This concept of automated drive cycle system can bring benefit to the automotive research.

1.3 Objective

Based on the issues outlined in the above section, this project aims to achieve the following objectives.

- I. Design a mechanism that can be used to control passenger vehicle according to standard drive cycles.
- II. Adapt the mechanism with a separate closed-loop control system to enable transient speed-load testing of a vehicle.

1.4 Scope of Study

Based on the limited time frame, this project will be focused on the following scope.

- I. The preliminary design will be based on a small capacity car
- II. The primary focus at this stage is to be able to produce a simple working prototype for a car with automatic transmission to avoid complexity of shift points found in manual transmission vehicles.
- III. The target for this initial stage is to have a basic mechanical working prototype for future development and integration with electronic control system.



CHAPTER 2

LITERATURE REVIEW

2.1 Fuel Economy and Emission of Road Vehicle

First self-power passenger carrier was built in 1769 by Nicolas-Joseph Cugnot. The first automobile was using steam piston engine [9]. Francois Isaac de Rivaz invented world first hydrogen powered internal combustion engine in 1807 and fitted into classic working vehicle in 1808 [10]. World first petrol driven internal combustion engine was invented by Etienne Lenoir and patented in 1859. In 1880, Karl Benz patented a two stroke engine powered by petrol in 1880. The first car invented by Karl Benz was a three wheeled car and the first four wheel car was produced in 1891. Start from that moment, the invention of engine and car was massive and more cars are produced [9].

The car produce after the World War II was design to be more in weight, bigger space and car size, more powerful in body material and engine power, which make it more expensive. The manufacturing of cars was controlled after enrollment of federal standards of automotive safety (1966), emission of pollutants (1965 and 1970), and energy consumption (1975). It is due to high consumption of fuel, safety and awareness of air pollution [10].

The effect of car based air pollution was discovered during year 1960's to 1970's [5]. On year 1973, the price of fuel in United States of America (USA) rise dramatically because of Organization of Arab Petroleum Exporting Countries (OAPEC) proclaimed an oil embargo to warn USA supplying Israel with arms. The crisis lead the USA to take action in order to low their fuel consume and balance the market need with their economy. It's also a step to control the effect of greenhouse and gas emission that haunt their environment [6].

The Energy Policy and Conservation Act of 1975 made their move in order to maintain the economy by releasing standard for car that will be sold in USA. The limitation is maximum of 25 miles per gallon (mpg) for each car. This will result in more distance covered with less usage of fuel car used which beneficial to the economy and customer [12]. The innovation and improvement was based on Figure 2.1 where the improvement required for better powertrain efficiency connected with technical approach, which have combustion as one of the important factor.

From the awareness of air pollution and also the needs for fuel efficiency, the standard has been tighter to increase the distance travel, consumption of fuel and the emission from engine. The standard that is used to calculate the fuel consumption and emission is first produced by North America and Europe, which is adopted by USA government. The test procedures need the vehicles to undergo several test to make it safe to be use and follow the standard that give out.

It is obvious that the more the speed of the car, the higher the consumption of fuel and the higher the carbon dioxide (CO_2) released to the surrounding. The test that undergo will determine the fuel consumption, the gas emission and many other criteria. There are two types of test that can be done, either by car chasing method or on board test. The car chasing method needs the car to be equipped with several equipment to collect the data needed. On board tests are done on a dynamometer, where the car will be driven by professional driver and parameters such as fuel consumption and emissions will be measured by using certain equipment [6].

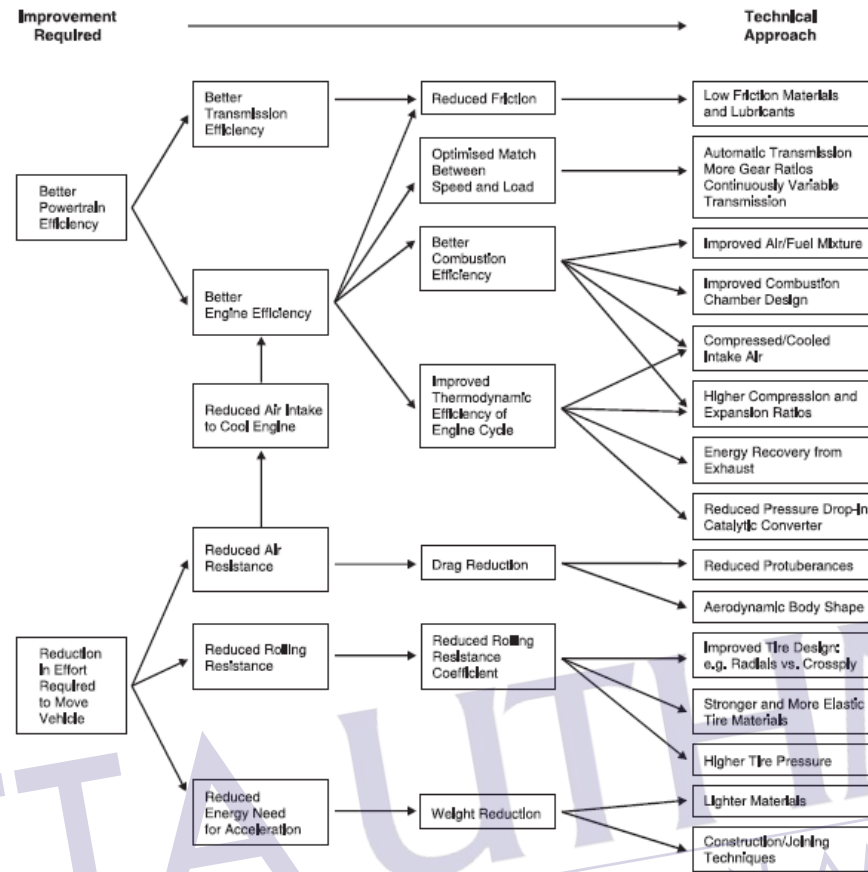


Figure 2.1 Technical Approaches to Reducing Fuel Economy of Light-Duty Vehicles
.[5]

2.2 Drive Cycles

Drive cycle tests are standard procedures that are being used to estimate car fuel consumption and emission. There are several drive cycles that has been used around the world. All the drive cycle procedures were derived from the Environmental Protection Agency: Federal Test Procedure (EPA: FTP). The type of light duty car is divided into several group that been classified by the year of the car manufactured and their emission as shown in Figure 2.2. The development of the drive cycle was improve continuously starting from year 1975 [5]. The following section describe each of the recent drive cycle used around the world.

<i>Model year</i>	<i>Carbon monoxide</i>	<i>Hydrocarbons</i>	<i>Nitrogen oxides</i>
Pre-1968 (uncontrolled)	90.0	15.0	6.2
1970	34.0	4.1	—
1972	28.0	3.0	—
1973-74	28.0	3.0	3.1
1975-76	15.0	1.5	3.1
1977	15.0	1.5	2.0
1980	7.0	0.41	2.0
1981	3.4	0.41	1.0
1994-96 (Tier 1)	3.4 (4.2)	0.25 ^a (0.31)	0.4 (0.6)
2004 (Tier 2) ^b	1.7 (1.7)	0.125 ^a (0.125)	0.2 (0.2)

Figure 2.2 Progression of U.S. Exhaust Emission Standards for Light-Duty Gasoline-Fueled Vehicles.[5]

2.2.1 Environmental Protection Agency: Federal Test Procedure (EPA: FTP-75).

The test is executed by car driven on a chassis dynamometer according to a predetermined speed-time trace (driving cycle). During the test the exhaust emission measured using Constant Volume Sampling (CVS) system, where the sample will be diluted and cooled [5].

CVS Sampling System

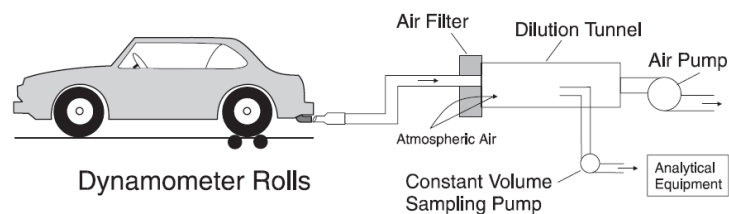


Figure 2.3: Constant Volume Sampling (CVS) layout.[5]

The driving cycle is undergone on duration of 2,475 seconds, replicates the various nature of urban vehicle operation situation (Figure 2.4). The average speed is 31.4 kilometers per hour. Between 1,370 and 1,970 seconds, the car will left to cool for about 10 minute when the engine is shut down. The speed vs time graph shown in Figure 2.3. The emission results calculate as the weighted average of emissions measured during three phases: cold start, hot stabilized, and hot start [5].

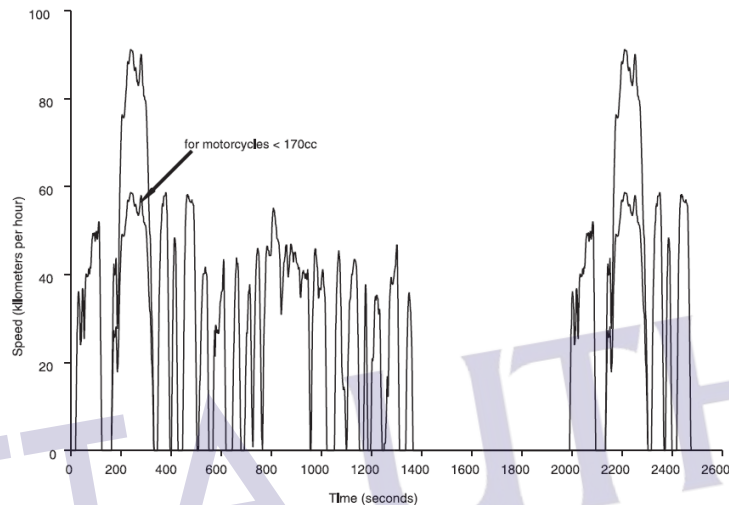


Figure 2.4: U.S. Emissions Test Driving Cycle for Light-Duty Vehicles (FTP-75).[5]

After the drive cycle done, the CVS system will measure the emission from the exhaust. The data from the test shown in Figure 2.5.

Standard	Year implemented	50,000 miles or five years			100,000 miles or ten years		
		Carbon monoxide 75°/20°F	Hydrocarbons	Nitrogen oxides	Carbon monoxide 75°F	Hydrocarbons	Nitrogen oxides
Passenger car ^a (Tier 0)	1981	3.4/—	0.41	1.0	—	—	—
Light-duty truck ^a (Tier 0)	1981	10/—	0.80	1.7	—	—	—
Tier 1 ^b	1994-6	3.4/10.0	0.25 NMHC	0.4	4.2	0.31 NMHC	0.6
Tier 2	2004	1.7/3.4	0.125 NMHC	0.2	—	—	—
California Low-Emission Vehicle/Federal Clean-fuel Fleet programs							
Transitional low-emission vehicle (TLEV)	1994 ^c	3.4/10	0.125 NMOG	0.4	4.2	0.156 NMOG	0.6
Low-emission vehicle (LEV)	1997 ^c	3.4/10	0.075 NMOG	0.2	4.2	0.090 NMOG	0.3
Ultra low-emission vehicle (ULEV)	1997 ^c	1.7/10	0.040 NMOG	0.2	2.1	0.055 NMOG	0.3
Zero-emission vehicle (ZEV)	1998 ^c	0	0	0	0	0	0

Figure 2.5: U.S. Exhaust Emission Standards for Passenger Cars and Light-Duty Vehicles Weighing Less than 3,750 Pounds Test Weight.[5]

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